7N64-31211

JOURNAL OF GEOPHYSICAL RESEARCH VOL. 69, NO. 15 AUGUST 1, 1964

Letters

Solar Modulation Effects on the Primary Cosmic Radiation near Solar Minimum

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Detailed measurements of the primary cosmic-ray charge and energy spectrums have been available only for the period following the last solar minimum (1954). While the balloon-borne ionization chamber results of *Neher* [1956, 1957] at high latitude indicated that striking increases occur in the low-energy galactic component during the time of solar minimum, it is difficult to infer charge and energy spectrums from these data. An extensive survey was undertaken by *McDonald and Webber* [1962, 1964] using the Cerenkov scintillator technique over the period 1955–1959. These measurements did not include the periods just before and during solar minimum when maximum ionization chamber values

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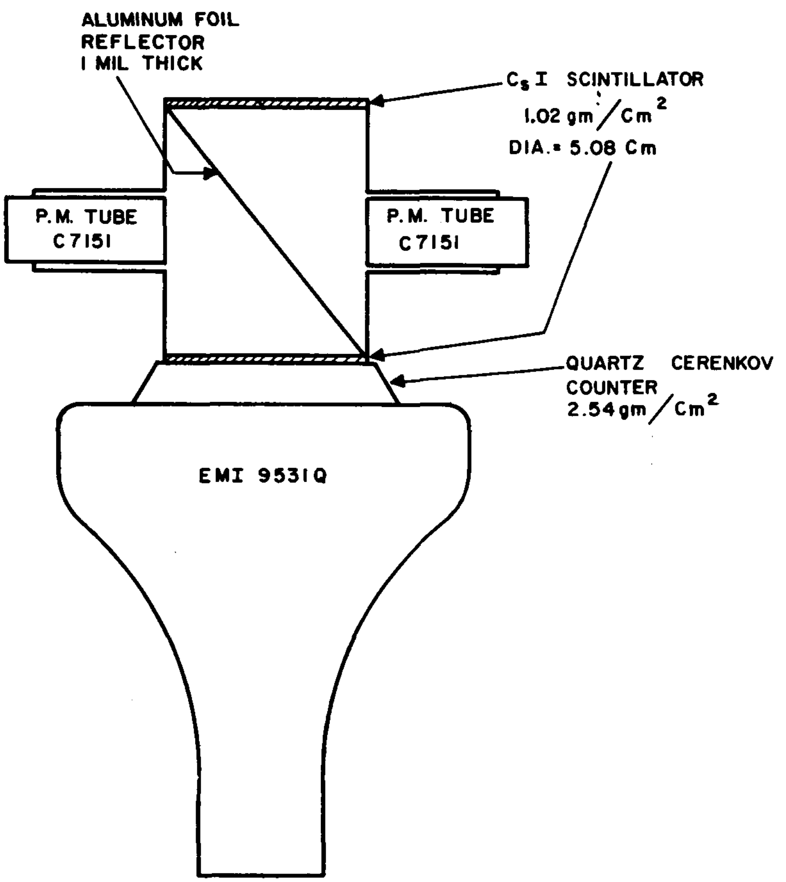

Fig. 1. The geometry of the double scintillator Cerenkov counter telescope. The geometrical factor is 4.46 cm² ster.

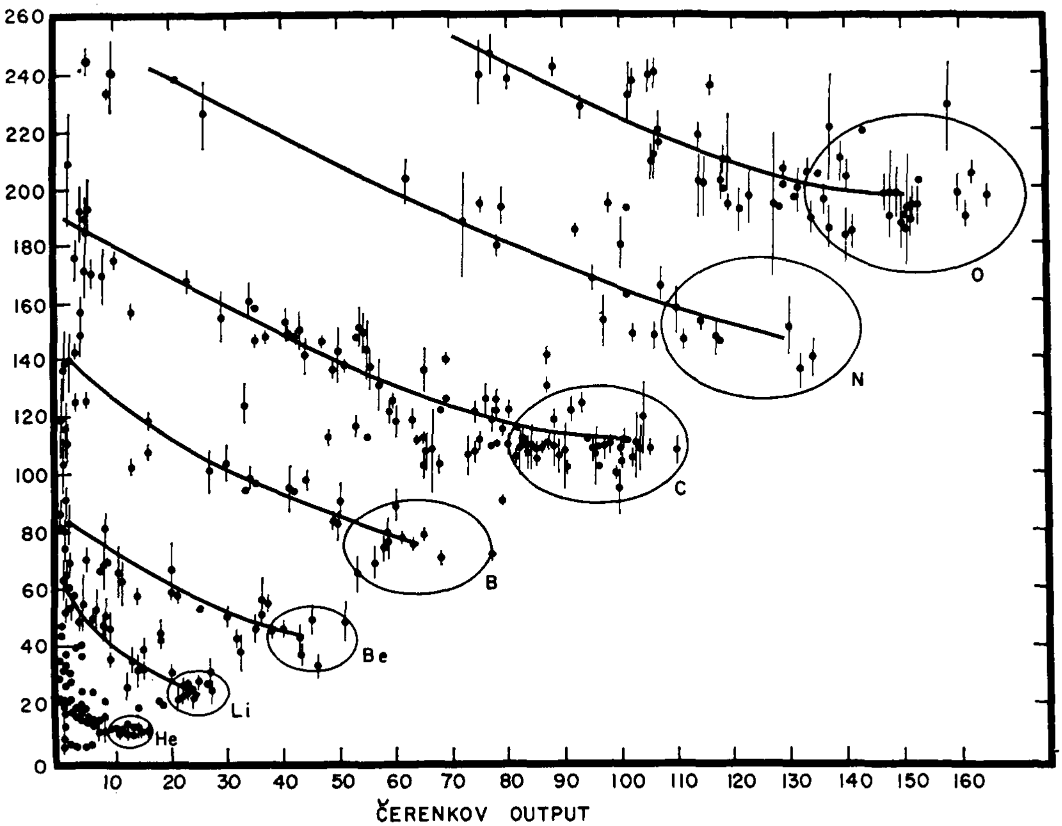

Fig. 2. Plot of Cerenkov output versus ionization loss in telescope. The end points of the individual lines represent the two measurements of ionization loss. A selection criterion has been applied which demands the two measurements to be within ±25 per cent of each other. An appropriate correction is made for Landau fluctuations.

were recorded by Neher, and the He spectrums in general did not extend below 1.2 bv. In order to cover this interval during the current solar cycle, a new series of balloon flights using an improved version of the Cerenkov scintillation counter has been initiated. This paper deals with the measurements obtained on a Skyhook balloon flight from Fort Churchill, Canada, in June 1963 of the differential H and He nuclei in the interval 100–600 Mev/nuc, the integral H and He flux >600 Mev/nuc, and the cosmic-ray charge spectrums in the range $Z = 1$–8. These measurements occur at a time of decreasing solar activity some 18 months before solar minimum.

A schematic drawing of the detector is shown in Figure 1. The system is similar in principle to that reported by *McDonald and Webber* [1962] except for some technical improvements to achieve better charge and energy resolution. For each particle traversing the telescope, the pulse heights from all three detectors are recorded. For each detector there is a 512-channel pulse height analyzer, and the data are recorded on a balloon-borne tape recorder.

During the flight on June 24, 1963, the balloon remained for 12 hours at a ceiling altitude of 5 g/cm^2. The equipment performed reliably throughout the flight, and the preflight and postflight calibrations were in agreement. The period during the flight was characterized by a quiet sun, with no apparent abnormal activity.

Figure 2 shows the charge resolution obtained in the region $Z = 2$–8. In the region >350 Mev/nuc (>5 Cerenkov pulse height) there is excellent resolution of all components. The L/M ratio at the observation level of 5 g/cm^2 for the energy range 400–800 Mev/nucleon is

0.36 ± 0.07, whereas for the energies above 800 Mev/nucleon the ratio is 0.36 ± 0.09. The ratio extrapolated to the top of the atmosphere by using the fragmentation parameters of *Friedlander et al.* [1963] is 0.28 ± 0.08, in agreement with the results at Texas (41°N) obtained by *O'Dell et al.* [1961] and *Fichtel* [1961].

The results on charge distribution obtained in this experiment are summarized in Table 1. Also shown there are results from previous measurements by other experimenters. There is no strong disagreement with the previous work. It is thought that the relative values of Li, Be, and B are perhaps more accurate than those generally obtained in emulsion experiments. However, the general agreement of the charge spectrums and the L/M ratio in measurements

TABLE 1. Comparison of Charge Distributions Obtained at the Top of the Atmosphere

	Charge Distribution, %						
Charge	Balasubrahmanyan and McDonald	*Waddington* [1961]	*Aizu et al.* [1960, 1961]	*Tamai* [1960]	*Fichtel* [1961]	*O'Dell et al.* [1961]	*McDonald and Webber* [1962]
Li	8.9	3.9	8.8	10.0	7.4	5.3	
Be	6.4	1.7	6.0	14.0	5.7	2.3	6.7
B	8.1	11.6	10.9	15.7	9.0	7.4	10.1
C	31.4	26.0	29.2	18.8	27.1	30.1	28.6
N	9.2	12.4	14.8	7.8	15.3	9.7	13.3
O	16.6	17.9	14.4	7.3	14.4	19.4	17.9
$Z > 10$	19.5	23.9	21.7	20.5	21.7	23.5	16.9

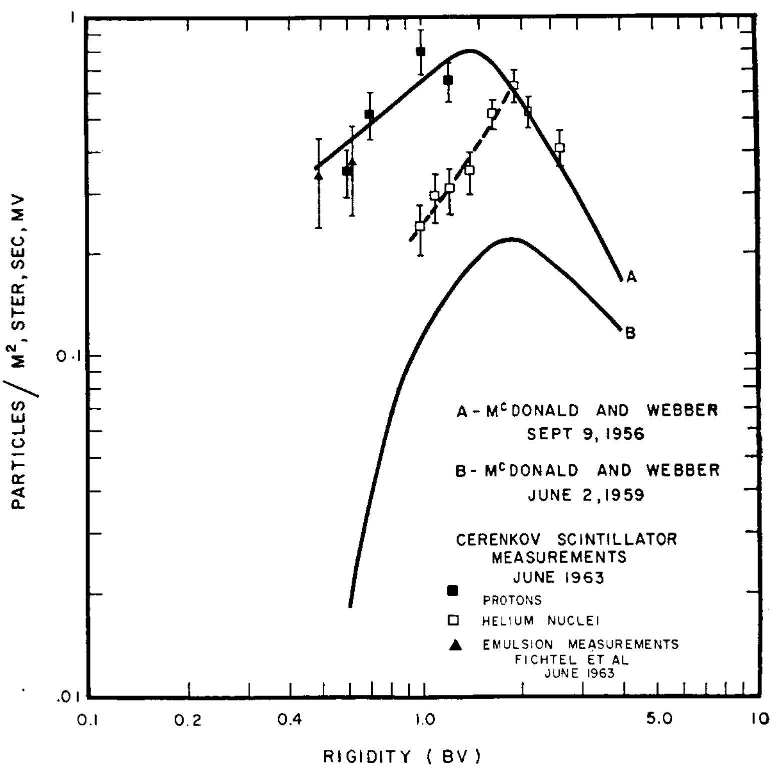

Fig. 3. Rigidity spectrums of protons and He nuclei.

covering a significant part of the solar cycle is striking.

The differential rigidity spectrums of H and He are shown in Figure 3. Both the method of analysis and the corrections applied are similar to those discussed previously by *McDonald and Webber* [1959, 1962]. The differential intensity of He nuclei at rigidities above 2 bv appears to have recovered to the value allowed in 1956. Below 1.5 bv it does not appear that the He component has reached its previous level. The recovery for protons has apparently been faster than for He nuclei of the same rigidity, since all points appear to agree with the 1956 data. Also shown in Figure 3 are the nuclear emulsion proton measurements of *Fichtel et al.* [1964*a*] for June 15, 1963. The good agreement between the results of these two entirely different experiments, particularly in the intensity measurements of low-energy protons where the secondary corrections, etc., are applied on an entirely different and independent basis, gives us a measure of confidence in the interpretation of these results and their bearing on the modulation process. The low-rigidity proton data above 0.6 bv appear also to be in good agreement with a reasonable extrapolation in time of the 1961 measurements of *Meyer and Vogt* [1963] and *Fichtel et al.* [1964*b*].

The most remarkable feature of these spectrums is the different forms displayed by the low-rigidity H and He spectrums. There is a sharp splitting of the two components below about 1.5 bv. Above this rigidity these components most probably have the same relative rigidity spectrums. The high-energy integral flux measurements and the shape of the differential curves lend weight to this argument. It is interesting to note that during the first half of the solar cycle no splitting was observed above 1.2 bv by *McDonald and Webber* [1964]; α-particle measurements below 1.2 bv were not available from their data. Such a splitting is not unexpected: most of the models proposed to explain the steady long-term (11-year) cosmic-ray variation contain velocity terms and thus predict a splitting of the two components if they have the same rigidity spectrums outside the solar system. It is hoped that further measurements near the solar minimum will make it possible to infer the galactic spectrums beyond the solar system, so that these results can be realistically compared with the theoretical models that have been devised.

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(Received May 5, 1964.)